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㊿発明の名称　Nd：YAGレーザーの第4高調波発生方法

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明　細　書

1.発明の名称

Ｎｄ：ＹＡＧレーザーの第４高調波発生方法

2.特許請求の範囲

1）Ｎｄ：ＹＡＧレーザー発振器の放射する基本波を第１の非線形光学結晶に入射させて、該第１の非線形光学結晶により基本波の一部から第２高調波を発生させ、該第２高調波と第１の非線形光学結晶を透過した基本波とを第２の非線形光学結晶に入射させて、該第２の非線形光学結晶により基本波の一部と第２高調波の一部から、第３高調波を発生させ、該第３高調波と、第２の非線形光学結晶を透過した基本波及び第２高調波をLiB_3O_5結晶よりなる第３の非線形光学結晶に入射させて、該第３の非線形光学結晶により基本波の一部と第３高調波の一部から第４高調波を発生させることを特徴とするＮｄ：ＹＡＧレーザーの第４高調波発生方法。

3.発明の詳細な説明

［産業上の利用分野］

本発明は高出力紫外線を必要とするレーザー化学、レーザーリソグラフィー、レーザー医療、バイオテクノロジー分野等に用いるＮｄ：ＹＡＧレーザーの第４高調波発生方法に関するものである。

［従来の技術］

従来、レーザー化学、レーザーリソグラフィー、レーザー医療、バイオテクノロジー分野等では、目的に応じて、レーザービームから高調波を発生させて利用することが行われており、この高調波発生の手順は第４図に示されている。

第４図中、１はＮｄ：ＹＡＧレーザー（ネオジウムドープドヤグレーザー）発振器、２はＣＤ＊Ａ結晶（CsD_2AsO_4結晶）等よりなる第１の非線形光学結晶、３はＢＢＯ結晶（β-BaB_2O_4結晶）、あるいはＫＤ＊Ｐ結晶（KD_2PO_4結晶）等よりなる第２の非線形光学結晶、４は60°分散プリズムである。

前記第２の非線形光学結晶３にＢＢＯ結晶を

用いる場合には、該BBO結晶の角度φが0°に、また、位相整合角θが48°になるようにカットを行っている。

また、第2の非線形光学結晶3にKD*P結晶を用いる場合には、該KD*P結晶の角度φが45°に、位相整合角θが90°になるようにカットを行っている。

なお、φ、θとは次のような角度をいう。

すなわち、第3図に示す如く、結晶体の光の屈折率をn_x、n_y、n_zとした場合に$n_x < n_y < n_z$となるx軸、y軸、z軸を想定し、原点を通って任意の方向に延びるベクトルのx－y平面への射影がx軸となす角度をφ、前記ベクトルのz軸となす角度をθとしている。

上述の構成において、Nd：YAGレーザー発振器1より基本波（波長λ_1＝1.0642μm）を放射すると、該基本波は第1の非線形光学結晶2に入射し、

$$\frac{1}{\lambda_2}=\frac{1}{\lambda_1}+\frac{1}{\lambda_1} \quad \cdots (1)$$

の関係に基づき、第1の非線形光学結晶2によって基本波の一部から第2高調波（波長λ_2＝0.5321μm）が発生する。

更に第2高調波と第1の非線形光学結晶2を透過した基本波は第2の非線形光学結晶3に入射し、

$$\frac{1}{\lambda_4}=\frac{1}{\lambda_2}+\frac{1}{\lambda_2} \quad \cdots (2)$$

の関係に基づき、第2の非線形光学結晶3によって第2高調波の一部から第4高調波（波長λ_4＝0.266μm）が発生し、該第4高調波と、第2の非線形光学結晶3を透過した基本波及び第2高調波は60°分散プリズム4に入射するとともに、該60°分散プリズム4によって分離され、分離された各高調波を所定の目的に利用している。

［発明が解決しようとする課題］

しかし、第2の非線形光学結晶3にKD*P結晶を用いた場合には、基本波よりも第2高調波のほうが、更に第2高調波よりも第4高調波のほうが近紫外線領域に近いため、前記KD*P結晶は紫外光の自己吸収によって熱影響を受け、位相整合条件が乱れて屈折率が変化し、第2図に示す如く、Nd：YAGレーザー発振器1を起動させてから約20分後には規格化出力が低下して光強度が0になるため、長時間安定した状態でNd：YAGレーザーの第4高調波を得ることができない。

また、第2の非線形光学結晶3にBBO結晶を用いた場合にも、前述したKD*P結晶と同様に紫外光の自己吸収によって位相整合条件が乱れKD*P結晶程ではないにしろ第2図に示す如くNd：YAGレーザー発振器1を起動させてからの時間経過に伴って規格化出力が低下するので、KD*P結晶を用いた場合と同様に長時間安定した状態でNd：YAGレーザーの第4高調波を得ることができない。

このため、従来は第2の非線形光学結晶3を温度制御装置によって加熱温度調整していたが、第2の非線形結晶3を一定温度に保持するのは難しかった。

本発明は上記問題点を解決するもので、非線形光学結晶の温度制御を行うことなくNd：YAGレーザーの第4高調波を長時間安定した状態で得られるようにすることを目的としている。

［課題を解決するための手段］

本発明はNd：YAGレーザー発振器の放射する基本波を第1の非線形光学結晶に入射させて、該第1の非線形光学結晶により基本波の一部から第2高調波を発生させ、該第2高調波と第1の非線形光学結晶を透過した基本波とを第2の非線形光学結晶に入射させて、該第2の非線形光学結晶により基本波の一部と第2高調波の一部から、第3高調波を発生させ、該第3高調波と、第2の非線形光学結晶を透過した基本波及び第2高調波をLiB_3O_5結晶よりなる第3の非線形光学結晶に入射させて、該第3の非線形光学結晶により基本波の一部と第3高調波の一部から第4高調波を発生させるものである。

［作　　用］

Ｎｄ：ＹＡＧレーザー発振器を起動させて基本波を放射すると、該基本波は第１の非線形光学結晶に入射して、該第１の非線形光学結晶により基本波の一部から第２高調波が発生し、また、残りの基本波は第１の非線形光学結晶を透過する。

第２高調波、及び第１の非線形光学結晶を透過した基本波は、第２の非線形光学結晶に入射して、該第２の非線形光学結晶により基本波の一部と第２高調波の一部から第３高調波が発生し、また、基本波、第２高調波の残りは第２の非線形光学結晶を透過する。

第３高調波、及び第２の非線形光学結晶を透過した基本波、第２高調波は、第３の非線形光学結晶に入射して、該第３の非線形光学結晶により基本波の一部と第３高調波の一部から、第４高調波が発生し、また、基本波、第３高調波の残り、及び第２高調波は第３の非線形光学結晶を透過する。

本発明においては、近紫外線領域に近い第３高調波が入射し、且つ第４高調波を放射する第３の非線形光学結晶を、紫外光の自己吸収が少なく、位相整合条件の温度許容幅の広いLiB_3O_5結晶により構成しているので、第３の非線形光学結晶が熱影響を受けて位相整合条件が乱れ、屈折率が変化して光強度の低下が非常に少なく、第３の非線形光学結晶の温度制御を行わなくても長時間安定した状態でＮｄ：ＹＡＧレーザーの第４高調波を得ることができる。

［実　施　例］

以下、本発明の実施例を図面を参照しつつ説明する。

第１図は本発明の方法を実施する装置の一例であり、図中、1はＮｄ：ＹＡＧレーザー発振器、4は60°分散プリズム、5は第１の非線形光学結晶、6は第２の非線形光学結晶、7は第３の非線形光学結晶を示す。

Ｎｄ：ＹＡＧレーザー発振器1が放射する基本波（$\lambda_1=1.0642\mu m$）を、ＢＢＯ結晶の角度を$\varphi=0°$、$\theta=48°$にカットした第１の非線形光学結晶5に入射し得るようにし、該第１の非線形光学結晶5によって基本波の一部から発生する第２高調波（$\lambda_2=0.5321\mu m$）、及び第１の非線形光学結晶5を透過した残りの基本波を、LiB_3O_5結晶の角度を$\varphi=37.8°$、$\theta=90°$にカットした第２の非線形光学結晶6に入射し得るようにし、該第２の非線形光学結晶6によって基本波の一部と第２高調波の一部とから発生する第３高調波（$\lambda_3=0.3547\mu m$）と、第２の非線形光学結晶6を透過した残りの基本波及び第２高調波とを、LiB_3O_5結晶の角度を$\varphi=60.7°$、$\theta=90°$にカットした第３の非線形光学結晶7に入射し得るようにし、該第３の非線形光学結晶7によって基本波の一部及び第３高調波の一部から発生する第４高調波（$\lambda_4=0.266\mu m$）と、第３の非線形光学結晶7を透過した残りの基本波、第２高調波、第３高調波とを60°分散プリズム4に入射し得るようにする。

上述の構成において、Ｎｄ：ＹＡＧレーザー発振器1を起動させて基本波（$\lambda_1=1.0642\mu m$）を放射すると、該基本波は第１非線形光学結晶5に入射して、該第１の非線形光学結晶5により基本波の一部から前記式(1)の関係に基づき第２高調波（$\lambda_2=0.5321\mu m$）が発生し、また、基本波の残りは第１の非線形光学結晶5を透過する。

第２高調波、及び第１の非線形光学結晶5を透過した基本波は、第２の非線形光学結晶6に入射して、該第２の非線形光学結晶6により基本波の一部と第２高調波の一部から

$$\frac{1}{\lambda_3}=\frac{1}{\lambda_1}+\frac{1}{\lambda_2} \quad \cdots (3)$$

の関係に基づき、第３高調波（$\lambda_3=0.3547\mu m$）が発生し、また、基本波、第２高調波の残りは第２の非線形光学結晶6を透過する。

第３高調波、及び第２の非線形光学結晶6を透過した基本波、第２高調波は、第３の非線形光学結晶7に入射して、該第３の非線形光学結晶7により基本波の一部と第３高調波の一部か

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ら

$$\frac{1}{\lambda_4}=\frac{1}{\lambda_1}+\frac{1}{\lambda_2} \qquad \cdots (4)$$

の関係に基づき、第４高調波（λ_4 ＝ 0.266μm）が発生し、また、基本波、第３高調波の残り、及び第２高調波は第３の非線形光学結晶7を透過する。

更に、第４高調波、及び第３の非線形光学結晶7を透過した残りの基本波、第２高調波、第３高調波は、60°分散プリズム4に入射して、該60°分散プリズム4により、基本波、第２高調波、第３高調波、第４高調波に分離される。

本発明においては、近紫外線領域に近い第３高調波が入射し、且つ第４高調波を放射する第３の非線形光学結晶7を、紫外光の自己吸収が少なく、位相整合条件の許容温度幅の広いLiB_3O_5結晶により形成しているので、第３の非線形光学結晶7が熱影響を受けて位相整合条件が乱れ、屈折率が変化して光強度の低下が非常に少なく、第３の非線形光学結晶7の温度制御を行わなくても第２図に示すように長時間安定した状態でＮｄ：ＹＡＧレーザーの第４高調波を得ることができる。

なお、本発明のＮｄ：ＹＡＧレーザーの第４高調波発生方法は、上述の実施例にのみ限定されるものではなく、本発明の要旨を逸脱しない範囲内において種々変更を加え得ることは勿論である。

［発明の効果］

以上説明したように、本発明のＮｄ：ＹＡＧレーザーの第４高調波発生方法によれば、下記の如き種々の優れた効果を奏し得る。

(1) 近紫外線領域に近い第３高調波が入射し、且つ第４高調波を放射する第３の非線形光学結晶を、紫外光の自己吸収が少なく、位相整合条件の許容温度幅の広いLiB_3O_5結晶により構成しているので、第３の非線形光学結晶が熱影響を受けて位相整合条件が乱れ、屈折率が変化して光強度の低下が非常に少なく、第３の非線形光学結晶の温度制御を行わなくても長時間安定した状態でＮｄ：ＹＡＧレーザーの第４高調波を得ることができる。

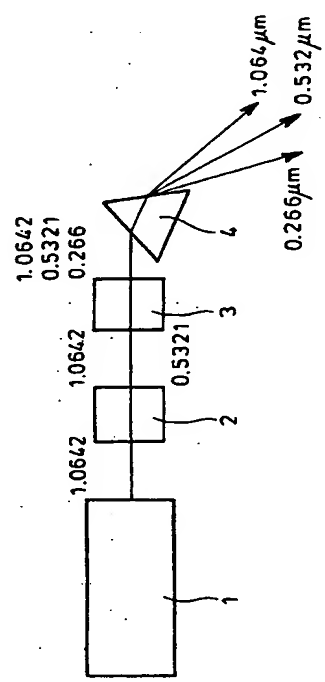
(2) 第２高調波は、第２、第３の非線形光学結晶を透過し、第３高調波は第３の非線形光学結晶を透過するので、Ｎｄ：ＹＡＧレーザーの基本波及び第２、第３、第４高調波の４波長を同時に得ることができる。

4. 図面の簡単な説明

第１図は本発明の方法を実施する装置の一例を示す概念図、第２図はＮｄ：ＹＡＧレーザーの第４高調波を波長変換する非線形光学結晶の光強度の安定性を示すグラフ、第３図は非線形光学結晶の位相整合角の概念図、第４図は従来のＮｄ：ＹＡＧレーザー装置の一例を示す概念図である。

図中、1はＮｄ：ＹＡＧレーザー発振器、5は第１の非線形光学結晶、6は第２の非線形光学結晶、7は第３の非線形光学結晶を示す。

第４図



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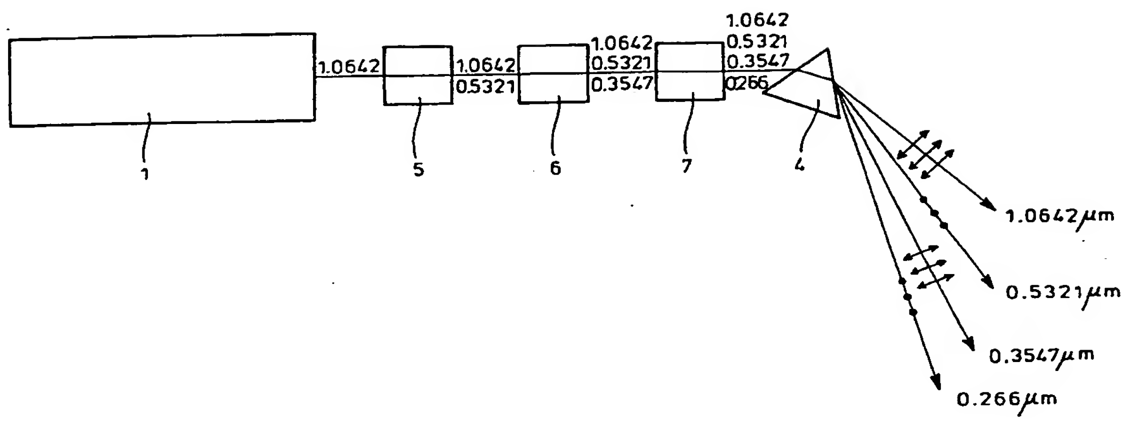
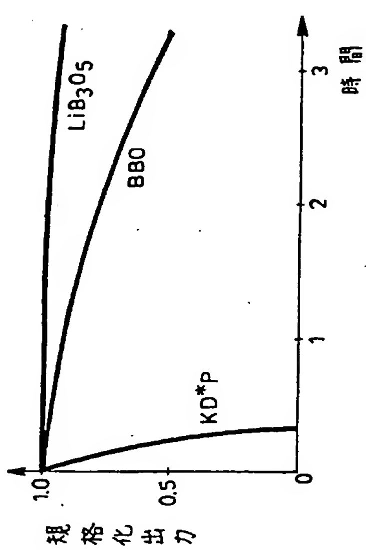
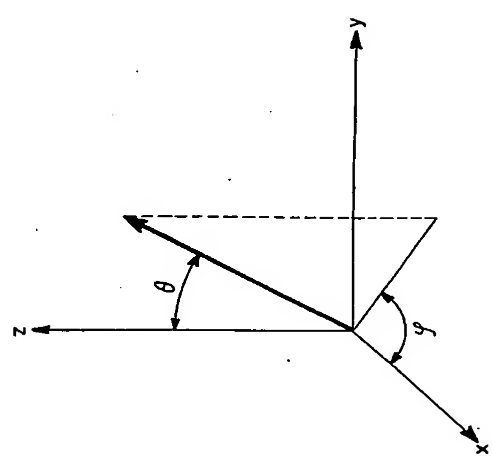
第 1 図



第 2 図



第 3 図



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SPECIFICATION

1. Title of the Invention: FOURTH-HARMONIC GENERATION METHOD FOR Nd: YAG LASER

2. Claim

1) A fourth-harmonic generation method for a Nd: YAG laser, wherein fundamental wave emitted from the Nd: YAG laser oscillator are made incident on a first non-linear optical crystal, second harmonic wave are generated from part of the fundamental wave by the first non-linear optical crystal, the second harmonic wave and the fundamental wave passed through the first non-linear optical crystal are made incident on a second non-linear optical crystal, third harmonic wave are generated from part of the fundamental wave and part of the second harmonic wave by the second non-

linear optical crystal, the third harmonic wave, the fundamental wave and the second harmonic wave passed through the second non-linear optical crystal are made incident on a third non-linear optical crystal including a LiB_3O_5 crystal, and fourth harmonic wave are generated from part of the fundamental wave and part of the third harmonic wave by the third non-linear optical crystal.

3. Detailed Description of the Invention

[Industrial Applicable Field]

The present invention relates to a fourth-harmonic generation method for a Nd: YAG laser used in the fields of laser chemistry, laser lithography, laser medical care, biotechnology, and so forth that require high-power ultraviolet rays.

[Related Art]

Hitherto, in the fields of laser chemistry, laser lithography, laser medical care, biotechnology, and so forth, harmonic wave were generated from a laser beam and used, as required. The process of the harmonic generation is shown in Fig. 4.

In Fig. 4, reference numeral 1 indicates a Nd: YAG laser (a neodymium-doped YAG laser) oscillator, reference numeral 2 indicates a first non-linear optical crystal including a CD*A crystal (a $C_sD_2A_sO_4$ crystal) or the like, reference numeral 3 indicates a second non-linear optical

crystal including a BBO crystal (a β - BaB_2O_4 crystal), a KD*P crystal (a KD_2PO_4 crystal), and so forth, and reference numeral 4 indicates a 60° dispersing prism.

Where the BBO crystal is used, as the second non-linear optical crystal 3, the BBO crystal is cut so that the angle φ thereof is 0° and the phase-matching angle θ is 48°.

Further, where the KD*P crystal is used, as the second non-linear optical crystal 3, the KD*P crystal is cut so that the angle φ thereof is 45° and the phase-matching angle θ is 90°.

The signs φ and θ indicate the following angles.

Namely, the x-axis, the y-axis, and the x-axis are given, where an expression nx < ny < n2 holds where the light refractive index of the crystal is shown as nx, ny, and nz. The angle which the projection of a vector that passes through the origin point and extends in a predetermined direction onto the x-y plane forms with the x-axis is designated by the sign φ and the angle which the vector forms with the z-axis is designated by the sign θ.

In the above-described configuration, where the Nd: YAG laser oscillator 1 emits fundamental wave (the wavelength λ_1 = 1.0642 μm), the fundamental wave are made incident on the first non-linear optical crystal 2 and second harmonic wave (the wavelength λ_2 = 0.5321 μm) are generated from part of the fundamental wave by the first non-linear optical crystal

2 according to the relationship shown as:

$1/\lambda_2 = 1/\lambda_1 + 1/\lambda_1 \quad \cdots \quad (1).$

Further, the second harmonic wave and the fundamental wave passed through the first non-linear optical crystal 2 are made incident on the second non-linear optical crystal 3 and fourth harmonic wave (the wavelength $\lambda_4 = 0.266$ μm) are generated from part of the second harmonic by the second non-linear optical crystal 3 according to the relationship shown as:

$1/\lambda_4 = 1/\lambda_2 + 1/\lambda_2 \quad \cdots \quad (2).$

The fourth harmonic wave, and the fundamental wave and the second harmonic wave that passed through the second non-linear optical crystal 3 are made incident on the 60° dispersing prism 4 and separated by the 60° dispersing prism 4. The separated harmonic wave are used for a predetermined object.

[Problems to be solved by the Present Invention]

However, the second harmonic wave are nearer to a near-ultraviolet range than the fundamental wave are and the fourth harmonic wave are nearer to the near-ultraviolet range than the second harmonic wave are. Therefore, where the KD*P crystal is used, as the second non-linear optical crystal 3, the KD*P crystal is under the heat influence by ultraviolet-ray self absorption and the phase-matching condition is not satisfied so that the refractive index

changes. Further, as shown in Fig. 2, about twenty minutes after the Nd: YAG laser oscillator 1 is started, the standardized output reduces and the light intensity becomes zero. Subsequently, the fourth harmonic wave of the Nd: YAG laser cannot be obtained for a long period of time with stability.

Further, where the BBO crystal is used, as the second non-linear optical crystal 3, the phase-matching condition is not satisfied due to the ultraviolet-light self absorption and the standardized output reduces as time passes after the Nd: YAG laser oscillator 1 is started, though not to the extent as is the case with the KD*P crystal, as shown in Fig. 2. Therefore, as is the case where the KD*P crystal is used, the fourth harmonic wave of the Nd: YAG laser cannot be obtained for a long time period with stability.

Therefore, in the past, heating temperature regulation is performed for the second non-linear optical crystal 3 by a temperature-control device. However, it has been difficult to maintain the second non-linear crystal 3 at a predetermined temperature.

The present invention is provided for solving the above-described problems and the object thereof is to obtain fourth harmonic wave of the Nd: YAG laser for a long time period with stability without performing the temperature

control for a non-linear optical crystal.

[Means for Solving the Problems]

In the present invention, fundamental wave emitted from the Nd: YAG laser oscillator are made incident on a first non-linear optical crystal, second harmonic wave are generated from part of the fundamental wave by the first non-linear optical crystal, the second harmonic wave and the fundamental wave passed through the first non-linear optical crystal are made incident on a second non-linear optical crystal, third harmonic wave are generated from part of the fundamental wave and part of the second harmonic wave by the second non-linear optical crystal, the third harmonic wave, the fundamental wave and the second harmonic wave passed through the second non-linear optical crystal are made incident on a third non-linear optical crystal including a LiB_3O_5 crystal, and fourth harmonic wave are generated from part of the fundamental wave and part of the third harmonic wave by the third non-linear optical crystal.

[Operation]

Where the Nd: YAG laser oscillator is started and the Nd: YAG laser oscillator emits the fundamental wave, the fundamental wave are made incident on the first non-linear optical crystal, the second harmonic wave are generated from part of the fundamental wave by the first non-linear optical crystal, and the remaining fundamental wave pass through the

first non-linear optical crystal.

The second harmonic wave and the fundamental wave passed through the first non-linear optical crystal are made incident on the second non-linear optical crystal, the third harmonic wave are generated from part of the fundamental wave and part of the second harmonic wave by the second non-linear optical crystal, and the remaining fundamental wave and second harmonic wave pass through the second non-linear optical crystal.

The third harmonic wave, and the fundamental wave and the second harmonic wave that passed through the second non-linear optical crystal are made incident on the third non-linear optical crystal. The fourth harmonic wave are generated from part of the fundamental wave and part of the third harmonic wave by the third non-linear optical crystal. Further, the other fundamental wave and third harmonic wave, and the second harmonic wave pass through the third non-linear optical crystal.

According to the present invention, the third harmonic wave near the near-ultraviolet range are made incident on the third non-linear optical crystal and the third non-linear optical crystal emits the fourth harmonic wave. The third non-linear optical crystal includes the LiB_3O_5 crystal, where the self-absorption for ultraviolet light thereof is limited and the temperature permissible width thereof that

is the phase-matching condition is large. Therefore, where the third non-linear optical crystal is under the heat influence, the phase-matching condition is not satisfied and the refractive index changes so that the light intensity hardly reduces. Subsequently, it becomes possible to obtain the fourth harmonic wave of the Nd: YAG laser for a long time period with stability without performing the temperature control for the third non-linear optical crystal.

[Embodiment]

Hereinafter, an embodiment of the present invention will be described with reference to the attached drawings.

Fig. 1 shows an example device for performing a method of the present invention. In this drawing, reference numeral 1 indicates a Nd: YAG laser oscillator, reference numeral 4 indicates a 60° dispersing prism, reference numeral 5 indicates a first non-linear optical crystal, reference numeral 6 indicates a second non-linear optical crystal, and reference numeral 7 indicates a third non-linear optical crystal.

Fundamental wave (λ_1 = 1.0642 μm) emitted from the Nd: YAG laser oscillator 1 are made incident on the first non-linear optical crystal 5 including a BBO crystal that is cut so that the angles thereof are shown by expressions $\varphi = 0°$ and $\theta = 48°$. Second harmonic wave (λ_2 = 0.5321 μm) generated from part of the fundamental wave by the first non-linear

optical crystal 5 and the remaining fundamental wave passed through the first non-linear optical crystal 5 are made incident on the second non-linear optical crystal 6 including a LiB_3O_5 crystal that is cut so that the angles thereof are shown by expressions $\varphi = 37.8°$ and $\theta = 90°$. Third harmonic wave ($\lambda_3 = 0.3547$ μm) generated from part of the fundamental wave and part of the second harmonic wave by the second non-linear optical crystal 6, the remaining fundamental wave and second harmonic wave that passed through the second non-linear optical crystal 6 are made incident on the third non-linear optical crystal 7 including another LiB_3O_5 crystal that is cut so that the angles thereof are shown by expressions $\varphi = 60.7°$ and $\theta = 90°$. Fourth harmonic wave ($\lambda_4 = 0.268$ μm) generated from part of the fundamental wave and part of the third harmonic wave by the third non-linear optical crystal 7, the remaining fundamental wave, second harmonic wave, and third harmonic wave that passed through the third non-linear optical crystal 7 are made incident on the 60° dispersing prism 4.

In the above-described configuration, the Nd: YAG laser oscillator 1 is started so that the Nd: YAG laser oscillator 1 emits fundamental wave ($\lambda_1 = 1.0642$ μm) and the fundamental wave are made incident on the first non-linear optical crystal 5. Further, the second harmonic wave ($\lambda_2 = 0.5321$ μm) are generated from part of the fundamental wave by the

first non-linear optical crystal 5 according to the relationship shown by the above-described expression (1) and the remaining fundamental wave pass through the first non-linear optical crystal 5.

The second harmonic wave and the fundamental wave that passed through the first non-linear optical crystal 5 are made incident on the second non-linear optical crystal 6, and the third harmonic wave ($\lambda_3 = 0.3547$ μm) are generated from part of the fundamental wave and part of the second harmonic wave by the second non-linear optical crystal 6 according to the relationship shown as:

$$1/\lambda_3 = 1/\lambda_1 + 1/\lambda_2 \quad \cdots \quad (3)$$

and the remaining fundamental wave and second harmonic wave pass through the second non-linear optical crystal 6.

The third harmonic wave, and the fundamental wave and the second harmonic wave that passed through the second non-linear optical crystal 6 are made incident on the third non-linear optical crystal 7, and the fourth harmonic wave ($\lambda_4 =$ 0.266 μm) are generated from part of the fundamental wave and part of the third harmonic wave by the third non-linear optical crystal 7 according to the relationship shown as:

$$1/\lambda_4 = 1/\lambda_1 + 1/\lambda_3 \quad \cdots \quad (4)$$

and the remaining fundamental wave and third harmonic wave, and the second harmonic wave pass through the third non-linear optical crystal 7.

Further, the fourth harmonic wave and the remaining fundamental wave, second harmonic wave, and third harmonic wave that passed through the third non-linear optical crystal 7 are made incident on the 60° dispersing prism 4 and separated into the fundamental wave, the second harmonic wave, the third harmonic wave, and the fourth harmonic wave by the 60° dispersing prism 4.

In the present invention, the third harmonic wave near a near-ultraviolet range are made incident on the non-linear optical crystal 7 and the third non-linear optical crystal 7 emits the fourth harmonic wave. Since the third non-linear optical crystal 7 is formed by the LiB_3O_5 crystal, where the self-absorption for ultraviolet light thereof is limited and the temperature permissible width thereof that is a phase-matching condition is large. Subsequently, the third non-linear optical crystal 7 is under the heat influence, the phase-matching condition is not satisfied, the refractive index changes so that the light intensity hardly reduces, and the fourth harmonic wave of the Nd: YAG laser can be obtained for a long period of time with stability, as shown in Fig. 2, without performing the temperature control for the third non-linear optical crystal 7.

Further, the fourth-harmonic generation method of the Nd: YAG laser according to the present invention is not limited to the above-described embodiment, but can be

naturally modified in various ways without leaving the scope of the present invention.

[Advantages]

As has been described, according to the fourth-harmonic generation method of the Nd: YAG laser of the present invention, various fine advantages can be attained, as below.

(1) The third harmonic wave near the near-ultraviolet range are made incident on the third non-linear optical crystal and the third non-linear optical crystal emits the fourth harmonic wave. Since the third non-linear optical crystal includes the LiB_3O_5 crystal, where the self-absorption for ultraviolet light thereof is limited and the temperature permissible width thereof that is the phase-matching condition is large. Subsequently, where the third non-linear optical crystal is under the heat influence, the phase-matching condition is not satisfied and the refractive index changes so that the light intensity hardly reduces. Therefore, it becomes possible to obtain the fourth harmonic wave of the Nd: YAG laser for a long time period with stability without performing the temperature control for the third non-linear optical crystal.

(2) Since the second harmonic wave pass through the second and third non-linear optical crystals and the third harmonic wave pass through the third non-linear optical crystal, four wave lengths including the fundamental wave

and the second, third, and fourth harmonic wave of the Nd: YAG laser can be obtained at the same time.

4. Brief Description of the Drawings

Fig. 1 is a conceptual illustration showing an example device for performing a method of the present invention, Fig. 2 is a graph showing the stability of the light intensity of a non-linear optical crystal for converting the wavelength of a fourth harmonic of a Nd: YAG laser, Fig. 3 is a conceptual illustration of a phase-matching angle of the non-linear optical crystal, and Fig. 4 is a conceptual illustration showing an example of known Nd: YAG lasers.

In those drawing, reference numeral 1 indicates a Nd: YAG laser oscillator, reference numeral 5 indicates a first non-linear optical crystal, reference numeral 6 indicates a second non-linear optical crystal, and reference numeral 7 indicates a third non-linear optical crystal.

Fig. 2

A: STANDARDIZED OUTPUT

B: TIME

Fig.1

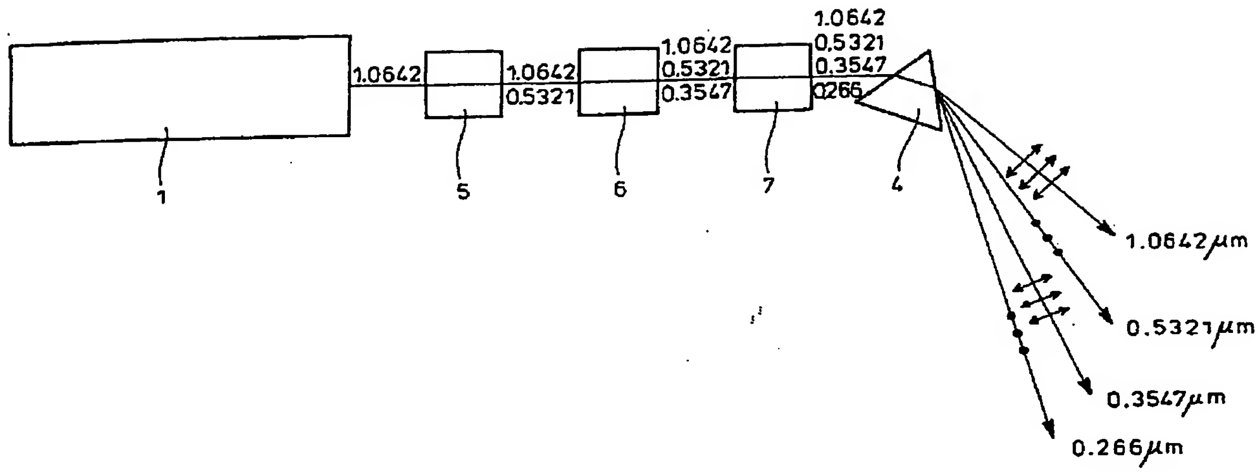


Fig.2

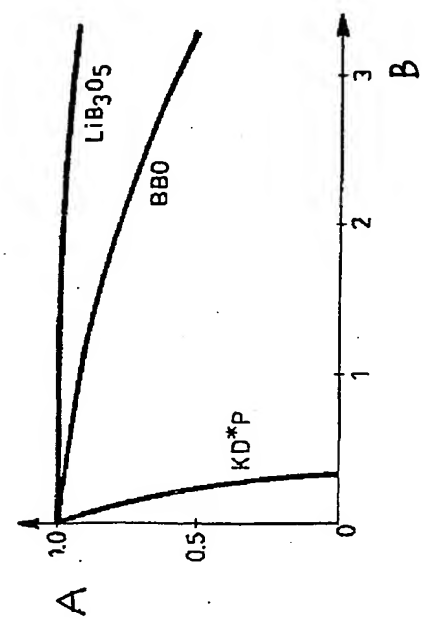


Fig.3

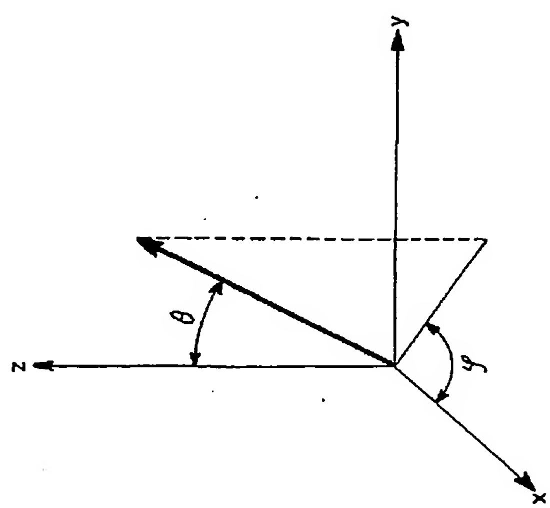
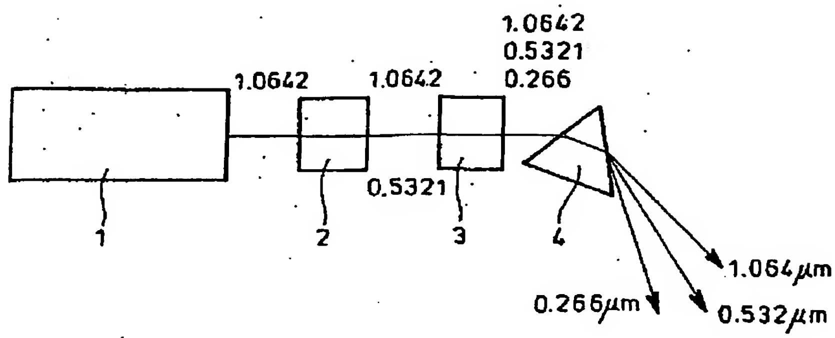


Fig.4


1.0642
1.0642
1.0642
0.5321
0.266
0.5321
1
2
3
4
1.064μm
0.266μm
0.532μm